1970

The submersible and oceanography.

King, Joseph Francis

Monterey, California. Naval Postgraduate School

THE SUBMERSIBLE AND OCEANOGRAPHY

by

Joseph Francis King

United States
Naval Postgraduate School

THESIS

THE SUBMERSIBLE AND OCEANOGRAPHY

by

Joseph Francis King

April 1970

The Submersible and Oceanography

by

Joseph Francis King
Lieutenant Commander, United States Navy
B.S., United States Naval Academy, 1959

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN OCEANOGRAPHY

from the

NAVAL POSTGRADUATE SCHOOL
April 1970

ABSTRACT

During a period of expansion of the nation's oceanographic effort, the submersible has seen a decline in utilization. This has resulted in several vessels being withdrawn from the market. The reasons for the lack of utilization of this oceanographic tool are studied in this paper.

The various national programs are examined to determine those data collection missions which require the unique capabilities of the submersible to utilize its ability to provide accurate alignment of instruments, conduct complex experiments "in situ" and core hard rock samples.

The submersibles failure to gain greater utilization results from its high cost and weather limitations and from the fact that its instrument suite does not provide a clear advantage over other methods of data collection.

It is concluded that the reduction of the pool of submersibles will not affect the progress of the nation's oceanographic efforts. Programs requiring such a vessel can be associated with national security, permitting research to be conducted with Navy operated submersibles.

It is also concluded the financial losses incurred by the owners of the submersibles will not deter further involvement by the private sector in the ocean development.

TABLE OF CONTENTS

LIST OF TABLES AND FIGURES

ACKNOWLEDGEMENT

Appreciation is expressed to those who have shared their time and experiences concerning this project. A special debt of gratitude is due Dr. D. F. Leipper and Dr. J. W. Creighton for guidance, counsel, and consideration. The experience and knowledge gained under their tutelage was vital to completion of this effort.

A debt of gratitude is also owed to Drs. R. J. Smith and E. C. Haderlie for the encouragement and contributions made toward this effort. Particular thanks is also due to Commander Don Walsh for his interest and efforts relative to this study.

Finally, thanks are due to my wife, Nicki, for her many hours of typing, but more importantly her extra understanding and assistance during the preparation of this paper.

I. INTRODUCTION

Interest in the sea has increased rapidly in recent years, and has led to the formulation of a comprehensive statement of goals for a national oceanographic effort. The manned submersible has been hailed as an essential tool to work toward these goals, but although the services of various submersibles have been utilized in geophysical, geological and biological experiments, there has recently been a decline in such utilization. It is desirable now to establish the true capabilities of the submersible in order to determine more exactly how it may best be utilized in carrying out the national effort. Those capabilities of submersibles which are unique should be evaluated in terms of the goals of the program and those capabilities which duplicate other systems should be evaluated for cost effectiveness.

A. DEFINITION OF TERMS

The definition of marine science provided in the establishing act of the Commission on Marine Science, Engineering and Resources, has been used in this paper.

The terms submersible and manned submersible are used interchangeably. Only dry manned submersibles were considered. The reference to unmanned vehicles will have a modifying prefix.

II. PURPOSE

The purpose of this study is to evaluate the role of the submersible in the broad field of marine science, particularly with respect to its cost effectiveness and to its unique abilities to support oceanographic activities.

A. NATURE OF THE PROBLEM

The development of the manned submersible has provided the oceanographer with a pool of vehicles which have the capability of delivering trained observers to 99% of the floor of the ocean. However, the potential provided by these vessels has seen little utilization in oceanography. The submersibles available to the scientists are being reduced in number as they are laid up or the sponsoring businesses fail [5][1]. It is necessary to determine if the loss of this potential will affect the ability to meet stated goals. The economic implication of the submersible and its influence upon participation in oceanography by the investment community also needs examination.

In order to assess the value of the submersible, it is first necessary to examine the current over-all oceanographic programs in which it might be used and then to determine the amount of fiscal support available.

The ocean affects all of us and provides complex problems of such a scope that a coordinated program of investigation is necessary. The

---

[1] Numbers refer to List of References.

cost of research in the ocean is high. It may be safely assumed it is beyond the fiscal resources of individuals. The Federal Government has proposed a coordinated program and provides funds for sponsoring much of the research which is required.

1. The National Goals

The national program in oceanography as discussed in this paper refers to "Our Nation and the Sea, a Plan for National Action" of January 1969, by the Commission on Marine Science, Engineering and Resources, hereafter referred to as the "Stratton Report". The Stratton Report was the result of a public law which charged the Commission to "make a comprehensive investigation and study of all aspects of marine science in order to recommend an over-all plan for an adequate national oceanographic program that will meet the present and future needs."

The report was comprehensive and addressed national goals in the following areas:

1. National capability in the sea
2. Management of the coastal zone
3. Marine resources
4. Global environment
5. Technical and operating service
6. Organizing a national ocean effort.

These broad areas were converted into national programs which pertain to specific problems.

There are several programs which do not have use for the submersible. These have been indicated by an asterisk, but they are included for completeness. Following is the full list of programs:

International cooperation and collaboration*
National Security
Fishery Development and Sea Food Technology
Transportation
Development of the Coastal Zone

Health
Non-living Resources
Oceanographic Research **
Education *
Environmental Observation and Prediction
Ocean Exploration, Mapping, Charting and Geodesy
General Purpose Ocean Engineering
National Data Centers *

* Submersible utilization not involved.

** Research beneficial to more than one of the other major programs.

The above programs are administered and conducted through eleven agencies. They represent the involvement of the Federal Government in marine science. A brief discussion of the above listed goals and programs is contained in Appendix A. The report summarized in the appendix has sought to provide knowledge of the nation's involvement in oceanography beyond the intuitive feel that is often held. The oceanographic effort affects a wide spectrum of activity controlled by a number of agencies. Despite the multitude of projects and agencies, a central control could be effected through the path proposed by the Stratton Report and in the interim the coordination of federal agencies is being provided by the executive branch of the government.

Reference 11 showed that non-federal research has involved all aspects of oceanography, but the areas that are stressed include management of the coastal zone, pollution control, port development, and development of oceanographic instruments and tools. As one large portion of this non-federal effort, the submersible industry has an on-going program designed to enhance the capability of their vessels and to improve their instrument suites.

2. Fiscal Support

Federal support for the major oceanographic programs since 1967 has been tabulated in Table I. The annual total of the federal programs

TABLE I

FUNDING OF NATIONAL PROGRAMS[2]

PROGRAM	FUNDING BY FISCAL YEAR (millions of dollars)			
	67	68	69	70
1. International Cooperation and Collaboration	7.1	9.6	9.5	11.7
2. National Security	161.8	119.9	128.1	143.0
3. Fishery Development and Sea Food Technology	38.1	40.1	43.8	44.5
4. Transportation	11.9	11.1	10.6	18.6
5. Development of the Coastal Zone	21.4	27.6	29.1	29.6
6. Health	6.6	5.3	5.4	5.3
7. Non-living Resources	7.2	7.3	8.0	8.6
8. Oceanographic Research *	61.5	78.1	93.3	93.5
9. Education	4.0	7.0	7.5	9.2
10. Environmental Observation and Prediction	24.0	28.8	31.6	32.1
11. Ocean Exploration, Mapping, Charting and Geodesy	77.4	75.7	83.0	99.1
12. General Purpose Ocean Engineering	14.8	19.2	18.3	29.5
13. National Data Centers	1.8	2.1	2.3	3.2

* Research that applies to several programs.

[2] Developed from ref. 35, 36 and 37.

has risen to in excess of $500 million, of which $300 million is primarily for research and development (R&D) efforts. The non-federal funds that are available are variously estimated to be as high as $125 million. A level of $55 million has been selected as most accurate [20].

This investment can be placed in perspective by a comparison to the size of the gross national product (GNP) and the total the nation allots to R&D. The former is $850 billion and the latter $25 billion [9 and 25]. The record since 1962 indicates a fixed ratio between the GNP and R&D allocation of 3%. This fact will be useful in estimating future developments. The R&D budget of oceanography is about 1.3% of the total R&D allocation by the nation.

Oceanography and its associated industries return from $1.5 to $25 billion dollars to the GNP. The extreme range of the estimates results from varying definitions of what should be included in this category by the agencies evaluating the total.

The major federal sponsor of marine science has been the Navy [3]. It has had a dominant position in oceanography due to the size of its marine science budget, a total of $287.2 million in FY 1969, 55% of the national program. A similar percentage applied for 1966, 1967 and 1968. The Navy's role is further strengthened by its large fleet of ships which can be used for oceanography and its ability to assign management and technical capability toward the solution of a problem.

The National Aeronautics and Space Administration, the Atomic Energy Commission, the Smithsonian Institution, the National Science Foundation, and the Departments of State, Commerce, Interior, Transportation, and Health, Education and Welfare have been the other major federal sources of fiscal support for marine science.

In addition to the Federal Government, thirty-six private firms have sponsored research [11]. The governments of twenty-two states, two cities and a large number of foundations and universities also provided research support. The number of non-federal sponsors of research has been placed at 95.

III. LITERATURE REVIEW

The operations and potential of the submersible have been well documented. The publication which has an encyclopedia quality is "The Deep Submersible" by Richard D. Terry. This has presented a fairly complete argument for utilization of this vehicle. Mr. Terry is an employee of North American Rockwell Corporation, the owner of Beaver IV.

The Interagency Committee on Oceanography (ICO) has a pamphlet "Undersea Vehicles for Oceanography." These two publications and the material provided by the firms that manufacture or lease submersibles has been the basis of the present evaluation of the submersible.

The above mentioned sources of data did not address the cost factor. In the present study, cost data has been obtained through direct inquiries to the owner of the vessel or, failing a reply from that source, the information was obtained from the Navy, if they had used the vessel in question.

Several corporations did not provide cost data. They voiced concern that this paper would not present the information in the proper light or that the options affecting the lease rate would not receive adequate explanation. Although data is incomplete, sufficient information was obtained to allow an analysis.

The limitations of the submersible have been, generally, overlooked in the literature. Data on these has been obtained by personal communication with submersible pilots, by discussions at industry presentations and seminars concerning the submersibles.

As previously mentioned, the goals of the national oceanographic program and its progress have been presented in the Stratton Report and in the annual report of the National Council on Marine Resources and Engineering Development. The Navy's role in support of the national program has been described in the "Project Blue Water" Report [3].

The pertinent parts of economic theory and data on the research and development as a whole were well documented in a variety of publications. The various authors have been in general agreement on the amounts and percentage of allocation of the R&D dollar.

Concurrently with the initiation of this study, it was announced that a budget item, amounting to $3 million, which was to cover leasing of submersibles for work in support of marine science, had been deleted. The instrumentation and other expenses associated with the project would have had to be paid from different sources of funds. There were in excess of 1600 requests for dives from the $3 million proposed fund. In response to requests from industry, Congress and the scientific community, an analysis of the requests has been conducted. The results of that analysis have been a source of information for this study [21].

IV. PRESENTATION OF DATA

The problem will be addressed in three specific areas.

1. Advantages
2. Uses
3. Costs of submersibles

A. ADVANTAGES

The discussion of advantages provides information on capabilities and limitations of the submersible. This section is presented in general terms. Specific submersibles are discussed only when a particular point may be given emphasis by so doing.

1. Capability

The submersible has several advantages over other oceanographic data collection systems. One unique characteristic is the possibility for the presence of man in situ.

The advantage is based upon the observers ability to take corrective and selective action during the data collection process. He has been able to repair equipment during a dive to allow continuation of the mission, or failing this, the observer has been able to modify the mission plan and to make observations that allowed future missions to capitalize on the aborted effort.

Reference 7 provides a discussion of such a mission where Aluminaut was attempting to recover an array of current meters in 3150 feet of water. During the initial dive two equipment failures occurred which affected buoyancy and navigation. Despite this, the vessel , by virtue of having men aboard, was able to locate the array

and ascertain that it was not fouled. The next dive accomplished the mission with ease, assisted by intelligence gained during the first event.

The second major advantage of a submersible is the ability to maneuver at the scene of the observations to assure complete coverage and an unobstructed view of the object of interest. This advantage is not unique, but is shared with the Controlled Unmanned Vehicle (CURV) to a depth of 2500 feet. Below this depth great difficulty is encountered in maneuvering unmanned sampling systems.

The last distinct advantage of the submersible is its ability to collect an integrated set of data at one location. It has carried instrument racks with equipment mounted to provide a complete spectrum of oceanographic data including television and photographic coverage of the scene. The man has the ability to assure that these complicated devices function. It is thus unnecessary to depend on a messenger and gravity on a kink-free wire. The significance of this feature has importance in relation to the "long handle" of oceanography. This traditional method of oceanographic data collection, by a cable with instruments affixed at various locations, was limited to one wire at a time due to the fear of fouling the wires. This physically limited the amount of equipment at one depth.

Although volumes have been written in favor of utilization of submersibles, the essence of their advantages is contained in the above factors.

2. Limitations

The limitations of the submersible in its scientific missions are primarily associated with the specific data requirement, however, the one common to all missions is the presence of the man.

Man, despite being the prime advantage, brings factors into data collection that are lacking in most mechanized systems. He has prejudices which affect his scientific judgment. The reflex reaction and attention span that he possesses have a tendency to degrade as he is placed in the stress of the submerged environment for extended periods. The submersibles, with the exception of Ben Franklin and Aluminaut, can be characterized as a confining environment with little personal comfort [17]. The lack of comfort has increased the seriousness of the limitation on effective performance.

The weather envelope in which the submersible may be launched and recovered has proven to be a severe limitation. The launch operations have been limited to sea state three or less, i.e. the significant wave height must be less than 3.5 feet and the wind less than 20 knots. However, a safe recovery of the vehicle can be conducted in a sea state of four. Several vehicles cannot be hoisted aboard a ship and must be towed to and from station. This has contributed to the severity of the weather limitation. The threat of bad weather along a tow transit route has forced delay of operations.

The submersible has been designed for the utmost in safety because it carries man. The vessel has several systems to assure the observers can execute an escape from any situation. The prime threat to safety which the submersible might encounter is entanglement. The procedures of diving have eliminated this threat, but in so doing have limited the tasks that can be undertaken.

There have been proposals that would employ the submersible as a monitor of trawling operations, or as a means of observing cable suspended instruments, as they operate at or near the bottom, to evaluate their performance. These proposals have not been carried out due to the possibility of entanglement with a parted wire or tow. The use of oceanographic cables from the tender has been prohibited while the submersible is operating.

Visual observations from most submersibles are made through windows with a limited field of view [15]. In most instances the overlap of the field between windows will not allow the observer and pilot to view the same object simultaneously. This affects maneuvering and the ability to discuss the experiments while they are underway.

The speed of most submersibles has been listed in the various publications in the range of 4 to 6 knots. Busby [15] indicated that actual operations have shown the speed to be less than one knot when operating near the bottom.

This slow speed is the result of pilot judgement, in many cases, since his field of sensor search does not guarantee he will not collide with the bottom or some object that rises from it. The low speed has increased the safety, but limited the ability to cover a region.

Busby and Costin [16] indicated the hydrodynamic configuration of some vessels caused oscillations as the speed was increased above two knots.

The remaining significant limitations or capabilities are associated with the physical characteristics of the vessel, its navigation equipment, ocean visibility and depth. These will be discussed when they affect the ability to accomplish roles or when they increase the cost of an operation.

The range of values for the physical characteristics are readily available in many publications. The table on page 21 of "Undersea Vehicles for Oceanography" [8] is relatively complete, but dated.

B. THE USES OF THE SUBMERSIBLE

The introduction stated that the marine science field is dominated by the Federal Government because of its heavy fiscal sponsorship. Thus, the scientific role of the submersible will be examined in relation to federal programs since the majority of operations have been in these programs. The roles that have evolved outside the marine science area and some of the projects that have been proposed by the submersible operators are discussed as separate topics.

1. The Role of the Submersible in Marine Science

Table II relates the scientific disciplines that involve potential roles for the submersible in the national effort. Since several of the programs have required the same type of observations to be made these roles will be discussed in relation to the data that would be collected by discipline rather than by program to avoid duplication of comment.

a. The Submersible in Marine Biology

The submersible has been proposed as the instrument platform to make observations and collect samples for the general topic areas listed under biology in Table II.

Some of the requirements relate to the assessment of marine biological resources, both for commercial and sport application, some to the study of life cycles and their inter-relationship with the

TABLE II

National Program vs. Data Obtainable from Submersible	National Security	Fish Development & Seafood Technology	Transportation	Dev. of Coastal Zone	Health	Non-living Resources	Env. Obs. & Prediction	Ocean Explo., Mapping, Geodesy	Ocean Eng.
<u>Biology</u>	x	x		x	x	x			x
Plankton & Nutrient		x		x	x	x		x	
Bottom Samples		x				x		x	
Cores, Grabs		x				x		x	
Sealife Specimens		x		x	x				
Type		x		x	x				
Population		x		x	x				
Life Cycle		x		x	x				
Deep Scattering Layer	x	x							
Fouling	x		x						x
Bio Luiminescence	x			x		x			
Coral Survey				x				x	
<u>Geophysical</u>	x		x	x		x	x	x	x
Gravity	x					x		x	
Geo-Magnetism	x							x	
Seismic Profiling						x		x	
Tidal Effects				x					x
Bottom Heat Flow							x		

National Program vs. Data Obtainable from Submerisble	National Security	Fish Develop-ment & Seafood Technology	Transportation	Dev. of Coastal Zone	Health	Non-living Resources	Env. Obs. & Prediction	Ocean Explo., Mapping, Geodesy	Ocean Eng.
Acoustics	x	x						x	x
Reflection	x								x
Scattering	x								x
Sound Vel. Profile	x						x	x	x
Sediment Transmission	x								x
Noise Level	x	x							x
Geology	x			x		x		x	x
Sediment Properties	x			x		x		x	x
Sub Strata				x		x			x
Coring						x			x
Rock Outcrops				x		x		x	x
Sediment & Transport						x			x
Turbidity						x			x
Suspended Sediment						x			x
Chemical	x	x			x				
Radioactivity	x								
Nitrogen		x							
Oxygen		x							
Phosphate		x							
Silicate		x							

National Program vs. Data Obtainable from Submersible	National Security	Fish Development & Seafood Technology	Transportation	Dev. of Coastal Zone	Health	Non-living Resources	Env. Obs. & Prediction	Ocean Explo., Mapping, Geodesy	Ocean Eng.
pH		x							
Salinity		x							
Trace Element	x				x				
Physical	x	x	x	x		x	x		x
Temperature	x	x	x	x			x		x
Currents	x	x	x	x		x	x		x
Ambient Light	x								x
Optical Properties	x								x
Turbulence							x		x
Internal Waves							x		x
Ice	x	x	x				x		x
Bathymetry	x		x			x			
Photographic Survey	x	x		x		x		x	x
Development of Equipment	x	x				x			x

physical characteristics of the ocean, and some to the improvement of methods of biological harvest.

The function of the submersible has been to enable the scientist to observe marine animal life and take selected, as opposed to random, samples to study bio-accoustics and to conduct operations in the deep scattering layer.

The nature of sea life is varied and its reaction to the presence of a submersible is not well known. It is doubtful if the presence of the large, noisy, lighted "monster" is ignored. To the contrary, Beebe [2] and Piccard [23] have discussed the close scrutiny given their submersible by various species on the one hand and the scattering of other sea life on the other hand, as it came into the field of their lights. To counter the reaction of the marine life, the submersible must be maintained in a darkened and quiet condition, then, by cycling the sensing devices and illumination, the sample might be surprised and observed.

An alternate procedure to obtain a similar sample would involve the lowering of an equipment rack with television cameras and a pulsed light. This array could be lowered while monitoring the progress on the television. The rack method would reduce the cost of the operation and in comparison with most manned vessels would have a longer data collection time. The rack could be launched in a sea state that is higher than that in which submersible operations are feasible.

The collection of particular samples by a submersible is limited to those forms of marine life that are attracted to the vessel or are slow enough to be overtaken by it.

The use of a television to determine the presence of the desired species, followed by a random sampling using a device such as a mid-water trawl, might obtain the desired animal without the cost associated with the use of a submersible.

The efficiency of existing marine harvest techniques, i.e., towed nets and drags, has been questioned. A proposal to utilize the submersible to monitor these operations has been made. However, the submersible has two limitations that affect this potential mission. The first of these results from a general reluctance to conduct dangerous operations in the vicinity of nets that might entangle the submersible.

Primarily the danger is present due to the limited range of light in the ocean depths. This requires the submersible to be in close proximity to the harvest mechanism for evaluation of the operation.

The second limitation is the speed of a submersible. At the speed of harvest operations, 2 - 5 knots, most submersibles are either not capable of following or have reduced mission length. However, the use of a camera or television with a pulsed light for recording the performance of a harvest mechanism may produce the desired data, and the noise and lights of the submersible which may bias the result of the experiment would not be present.

For reasons similar to those listed above, a camera or television equipment packages on a rack allow collection of data in the deep scattering layer that would produce data comparable to that obtained by the submersible on the same mission.

b. The Submersible in Marine Geology

Geology has a major role in many of the national programs. It is concerned with the location of mineral resources, origin of the structures and formations on the ocean floor and the origin, thickness and strength characteristics of the ocean sediments.

The submersible role in marine geology is wide spread and significant [29 and 41]. The economic development of the ocean requires an accurate geologic map. The development of such a map is limited by the lack of accurate bathymetric maps, and a set of representative samples of the ocean bottom. (The problems associated with making a bathymetric chart are discussed in conjunction with the use of the submersible in physical oceanography.)

The limited speed of submersibles and the low visibility in the sea make the construction of a large scale geologic map beyond the capability of a submersible. On the other hand, a "fish" towed from a surface ship with fathometer and photographic devices allow wide coverage. The chart can then be constructed from the photograph and the submersible may be utilized to investigate points of particular interest. The relative merits of the submersible with a geologist as an observer as opposed to the "fish" have been widely debated; however, the economic factor has caused the latter to be the more widely used.

Making the geologic map requires representative rock samples from outcrops to depict the substrata. Attempts to pick these rocks from the ocean floor, whether made by a trained observer in a submersible or by a bottom drag, have a high probability of failing to find representative samples since the loose rocks may not be from local strata. The preferred method for assuring a true sample is to

obtain it from a rock outcrop. Such hard rock samples have provided reliable data concerning the formation of the earth's structure.

The National Science Foundation is sponsoring a program, with an estimated cost of $34.8 million to allow the drilling of the ocean floor. This program is being conducted from the "Glomar Challenger". Although the submersibles have a limited ability to obtain cores, (about 12 inches into hard rock [42]), the concept of utilizing such vehicles to support the program of bottom investigation for hard rock bottom truth would expand the national capability beyond that of the unique Glomar Challenger.

This program, even without the supplemental use of the submersibles, has produced economic return by the discovery of oil deposits in the Gulf of Mexico.

The role of the submersible as a means of transportation for the trained observer to witness sediment transport and turbidity currents has limited applicability. These events occur on a long time scale or are unpredictable. Also, the submerisble is not needed since photographic surveys over a long period from surface ships have the potential to reveal the pattern of sediment motion. Further, the implantation of some yet-to-be-developed device on the ocean bottom may provide a method to analyze turbidity currents. Such a mechanism could employ a photographic element actuated when the sediment content of the water reached a "trigger" level.

The submersible has ability to conduct a wide variety of experiments and collect samples of the sediments. Currently the strength of the sediments are being estimated from samples obtained by a variety of coring and grab techniques. The samples are disturbed

physically during the collection operation. The pressure of the water in the sample is relieved, during the raising to the surface, further affecting the strength properties. The engineering properties of sediments have an affect on the ability to occupy and exploit the ocean bottom. The load bearing capacity determines the feasibility of construction of habitats or remotely operated production facilities.

Various instruments have been developed for use from the surface for "in situ" determination of such engineering properties as capacity to resist penetration, compressibility, slope stability and shear strength. To date, they have not provided meaningful results. The path of determination of the relationship between "in situ" and laboratory results lies in the accomplishment of a series of controlled experiments utilizing the submersible for "in situ" observation and comparison of the results of these experiments with those obtained from conventional samples at the same location. Until this relationship has been discovered, the safety factors utilized in ocean floor construction, about 5 to 7, as opposed to a desirable 1.5 to 2, place a severe economic handicap on progress in exploitation of the ocean floor.

c. The Submersible in Marine Geophysics

The exact position of points on the earth's surface, the strength of the gravity and magnetic fields, and variations therein, represent the major goals of the geophysics discipline in oceanography. These are vital to national defense in its application to Polaris missile navigation and submarine location devices such as Magnetic Anomaly Detection (MAD) equipment.

The submersible has the capability to function in the collection of the required data, however, navigation accuracy problems and limited range have resulted in its utilization being limited to technical demonstration of capability. This is in contrast with the fact that initial at-sea gravity measurements were made from submersibles, due to their ability to operate below the wave effects. The principal thrust of technology, in this area, however, has been toward satellite and airborne collection of data [3].

The flow of heat from the earth into the ocean floor affects the near bottom currents and causes a slight rise in the sea water temperature as the bottom is approached. Temperature profiles through the bottom sediment and the first few meters of the water will allow determination of the heat flow. The alignment of the temperature probe is critical to these measurements. The submersible has provided the ability to conduct these experiments, except that penetration of the probe to the desired depth might not be feasible due to buoyancy control limitations.

A seismic study capability has been demonstrated from submersibles, but this technique normally offers no clear cut advantage over surface procedures. However, an ice covered region such as the north coast of Alaska has provided a situation where seismic information is vital and surface techniques impractical. A fleet of submarines will be utilized in this region to collect seismic data in connection with the recent oil field discoveries.

d. The Submersible in Marine Chemistry

Marine chemistry has been concerned with the distribution of the chemical constituents of the sea water, corrosion and the

engineering properties of materials. The roles proposed for the submersible have included collection of samples and "in situ" determination of the concentration of constitutents.

Recent advances in technology have provided instruments that electronically determine element concentrations with an accuracy comparable to good laboratory techniques. The oxygen and salinity determining devices have been made commercially available.

The trace elements, which may relate to radioactivity, are present in such small amounts that concentration techniques or X-ray identification procedures are required to determine amounts present. These cannot be accomplished from any presently available submersibles due to space and power limitations. Effective sampling techniques for observing the distribution of chemical constituents are available from surface vessels.

The effects of the ocean on materials through corrosion and other processes are little understood. To date, ocean simulation facilities have been used in the majority of tests involving material performance. These allow simulation of many of the parameters in the actual ocean. One of the major problems with simulation is the lack of the biologic element that can be critical in the performance of the substance under test. The ability to correlate the results of tests at various sites due to a lack of modeling standards has limited the usefulness of much of.the data obtained from these tests [43].

The Naval Civil Engineering Laboratory (NCEL) has conducted a test of materials, which were placed in the ocean for extended periods. The results of the test showed the chemical and biological factors that could be expected to affect the material. An

extension of this test would be a program that placed the samples in the ocean under a load, to allow a determination of the strength of the material in its proposed configuration.

The submersible would have a role in the monitoring of test progress. It would allow the element loadings to be adjusted without removing them from the test environment. The amounts that have been spent on ocean simulation facilities would underwrite an aggressive program for determination of material performance under actual conditions.

e. The Submersible in Acoustics

The use of sound in the ocean is analogous to light in the atmosphere. Just as there is a day and night with its affect on the ability of the eyes to function effectively, so are there varying conditions in the seas that affect the results obtained from the sonic instruments.

In order to conduct studies of the variation of the acoustic signals as a function of water conditions and range to the source, a mobile source or receiving system is required. The submersible has been used extensively as a mobile instrument platform for these tests.

The scientist has formulated theories that predict the affect of the ocean on sound; however, anomalous behavior has been noted. The principal regions of doubt are concerned with the water sediment interface and the distribution of concentrated acoustic energy in the convergence zone. The submersible has been used to conduct experiments that examine these anomalies. Since sound is directional, the alignment of the instruments is critical in acoustic

experiments. The use of the submersible has allowed some desired results to be obtained. Due to the lack of control over the alignment, the use of an instrument controlled from the surface has not provided assurance of obtaining the necessary accuracy.

The submersible has been used to collect sediment samples and conduct in situ tests so that the correlation between the experiments under actual conditions and laboratory results would be determined. This should result in improved sonar prediction capabilities for the various types of ocean bottoms.

A region of scientific interest combining acoustics and biology has been labeled bio-acoustics. This involves the study of noise generated by sea life. Studies of the source and nature of this noise are being conducted. The problem of relating noise to source has been difficult. It has been proposed that an observer be placed in the submersible in an attempt to determine and visually identify the source of the emission and to determine the reason for the noise where possible.

Acoustics probably will remain a keystone in oceanographic research. The study of acoustic paths, reflection, and absorption of sound under varying water conditions will be an on-going program for at least several years. The importance of these studies to our national defense can be judged from the level of funding for projects associated with acoustics. For example, the USS Dolphin, an acoustic research submarine, was built at a cost in excess of $30 million.

f. The Submersible in Physical Oceanography

Physical oceanography is concerned with the determination of the values of certain parameters such as temperature, density,

salinity and optical properties, and their time and space variations. It is also concerned with the boundaries of the ocean including the wave disturbed surface and the uncharted depths. The submersible has been outfitted to measure each of these parameters. It has also been used on drift missions to move with the ocean currents.

The measurement of these properties and boundaries has also been conducted from a variety of surface vehicles and with remotely controlled devices. The use of sampling devices controlled from a submersible as opposed to use of the oceanographic cable has offered an advantage in that the actuation of the sampling device is monitored.

Ocean currents have been determined by anchored mechanisms and free floating devices. The problems associated with the anchored devices have been calibration, sensitivity and inability to recover the data due to the failure of release mechanisms. The free floating devices, principally the Swallow float have also presented problems, one of which has been the fact these systems are not recovered and that a large economic investment is thus required to obtain data.

Ben Franklin, a deep submersible, was designed for lengthy current drift missions. This vehicle was capable of concurrently conducting a variety of oceanographic experiments, and has provided information on man's ability to operate in a controlled environment.

Other submersibles have also been used to investigate ocean currents by drifting and by implanting current measuring devices and later retrieving them.

Bathymetry has presented a problem which calls for dual solution; navigation charts and bottom contour charts. Sound signals

have been used, almost exclusively, for determination of depth. The spherical spreading of the sound beam has resulted in some of the bottom detail being masked due to the sound signal returning first from the nearest object that is encountered. The loss of bottom detail is not crucial to the navigation chart since most ship's fathometers have been calibrated to provide data that corresponds to the chart, thus allowing the navigation to be based upon the soundings. The use of depth data obtained from a submersible will cause the above mentioned correspondence to be lost. The bottom charts essential to geologic maps must be constructed from data collected by devices that maneuver close to the bottom to ensure that the required detail has been obtained. This has been accomplished from submersibles and by using towed instrument platforms. The former has an advantage in its ability to easily maneuver near the bottom, the latter has greater range and costs much less to operate than a submersible. The placing of a television on a sled has provided a method for a direct observation of the terrain. This was formerly an advantage unique to the submersible.

2. <u>Role of the Submersible Outside of Marine Science</u>

The following discussion concerns markets for the submersible's potential which are not included in "marine science". These markets are; salvage, recreation, and underwater inspection and maintenance. The submersible has also been used for archeology. At present, these markets present a limited demand for submersible services; however, each area has the potential to expand greatly.

a. Underwater Inspection and Maintenance

The submersible is being used to monitor and control the operations of the systems in the off-shore oil fields. This includes inspection of pipelines, cables and visual observation of evolutions. It is used to transport diving service teams with a lock-in lock-out ability which has greatly extended the diver's ability to perform useful work.

The submersibles have used their manipulator to make mechanical adjustments and repairs at the ocean test ranges and in the oil fields.

It has a potential role in the servicing of completely submerged oil production sites. The problems of oil production, such as unsightly rigs, oil spills and cost of maintenance of off-shore towers have fostered efforts to incorporate the well and all auxiliary equipment in a submerged unit that will be periodically serviced by manned submersibles. Systems have been proposed by North American Rockwell and Lockheed Missile and Space Company which incorporate these features. North American's submersible, Beaver IV, was designed as an integral part of this concept.

The role of the submersible in support of off-shore drilling evolutions is assured as the operations progress into the waters beyond the depth capability of divers who currently do much of the work [13 and 28].

b. Recreation

The expanding area of recreation has presented opportunities for the submersible. The most ambitious effort involved the Auguste Piccard which was used to convey passengers to the depths of Lake

Geneva during the 1965 Swiss Exposition. With a capacity of 40 passengers, 30,000 paying customers were carried to depths of 200 feet. Upon completion, the vessel was used for 20 research dives to determine the origin of the lake.

The Auguste Piccard with a designed depth capability of 2500 feet was never used below 1,000 feet. It is now laid up and available for a price of $200,000 [7].

Small vessels such as Kittredge and Amersub 300 provide a diversion for those who seek adventure and have the funds to support their taste.

c. Salvage

The recovery of objects from the ocean floor is an area of submersible usage which has wide potential and a history of dramatic success.

The most significant single salvage operation was the recovery of the nuclear weapon that was lost off the shore of Spain. This operation employed a variety of devices to locate and recover the weapon, however, Alvin and Aluminaut were vital to the success of the operation. The cost of $340 thousand for submersible services in connection with this salvage operation must be evaluated as a bargain when compared with the cost to the nation's reputation if the recovery operation had failed, or if some other nation had salvaged the weapon.

The recent recovery of the Alvin by the operations of Aluminaut was another demonstration of this type of operation. Again the worth of the object recovered far exceeded the cost of the location and recovery operation.

Pisces is under contract at the Keyport Naval Station to recover weapons at a test range. It has been able to conduct a profitable operation on a fixed fee per torpedo recovery. In addition to this, it salvaged a 95 ton tug that had sunk in 670 feet of water. This depth was beyond the ability of any other system to recover the tug.

Deep Quest was able to conduct a detailed search in a cluttered area and recover the flight recorder from two aircraft that had crashed into the sea off Los Angeles. Financially self supporting operations in salvage from wrecks is a field for the submersible that has the potential to employ the entire submersible fleet.

d. Archeology

Archeology has been conducted by Asherah, and was its primary mission during the period it was owned by the Museum of the University of Pennsylvania. Bass and van Doorninck [12] have reported on the use of submersibles in this type of operation.

3. Industry Proposals

The corporations that have produced the submersibles have also proposed utilization of their vessels. These proposals have seemed to stress dramatic accomplishment rather than an orientation toward national programs seeking an economic return in the near future and an increase in the broad base of scientific knowledge.

Markel [10] proposed a mission that is of particular interest. This was the utilization of Aluminaut for a company sponsored salvage mission of a sunken antique vessel from deep water. The valuables that are recovered will be used to sponsor a national manned exploration of the seas program. The national manned exploration

of the sea has been referred to as a "Lewis and Clark" expedition to visually explore the ocean floor. The cost of this expedition is usually discussed in relation to the space program and the potential for economic returns.

The tracking of food crops, in particular shrimp and lobster, to observe the life cycles and improve the yield of these species has been discussed. The life cycle of a lobster covers years. To obtain the required data would cost in the millions of dollars. The lobster is a money crop, but will it be found in numbers that would warrant the large investment in opposition to an investment in those fish that can be readily converted into fish protein concentrate which is needed in large amounts now?

Another proposal was the determination of ocean currents by having the submersible track a free floating buoy and fixed reference. The precise measurement of surface waves from the stable submersible has also been suggested. The above tasks may be within the mission profile of many submersibles but are they needed now? Is the submersible the best means of accomplishing it? The answer is usually no.

The national goals were established with the aim of meeting resource shortages that were foreseeable and to provide an understanding of the ocean and its potential to allow an orderly exploitation of it.

Unless a new source of funds to support submersible operations is developed, such as the salvage operation, the chance of these company suggested operations being undertaken is small.

C. THE COST OF USING A SUBMERSIBLE

The terms expensive and economical apply on a relative scale. However, by most standards, submersibles may be listed as expensive. The range of lease rates have extended up to $16,000 per day and construction fees of $5 million are not uncommon. The decision to increase research funding must be preceded by careful examination of the scientific and economic factors that relate to the use of the submersible. It is the purpose of this section to address cost and cost effectiveness problems as they relate to the submersible, such as the cost of a lease, the cost of ownership, why the submersibles have been built and some effects of the failure to use the submersible by the oceanographers.

1. The Cost of a Lease

Submersibles are normally leased to make scientific observation. In most instances the instruments used are the same as would have been suspended from a surface vessel by cable. The instrument suite required for the scientific observation is not provided when leasing a submersible or a surface vessel. The leasee is required to obtain the instruments independent of the vessel. Comparison of instrumentation then is at most only a minor factor in the analysis of the cost in the use of a submersible and it will not be considered.

Table III presents the lease rates for various submersibles. The lease rate is the cost of the vessel, crew, and a basic set of lights and navigation instruments. The rate is a representative value which is affected by several factors which can cause adjustments. The factors are length of lease, non-dive transit days, equipment failure and multiple dive days. The first three will reduce the daily rate while in most cases multiple dives incur an added fee.

TABLE III[3]

LEASE RATE FOR SUBMERSIBLES

Name of Vehicle	Lease Rate Dollars/day	Approximate Cost of Support Ship
PC3	700	600
Nokton	1,000	
Star II	2,000 to 2,500	
PC8	700	600
Beaver	5,000 to 8,000	1,300
Deepstar 4000	5,000	2,000
DOWB	2,600	1,600
Aluminaut	2,500 to 16,000	

COST OF MANUFACTURE

Name of Vehicle	Cost	Depth (ft)
Turtle	5.5 million	6,500
PC8	125 thousand	1,000
Ben Franklin	5.25 million	2,000
Guppy (tethered)	148 thousand	1,000
PC9C	300 thousand	1,200

[3]Developed from references 1, 6, 19, 22, 24 and 27.

Another area of expense when using the submersible is the number of support personnel required; for a Perry Submersible, for example, either PC 5 or PC 8, there is a need for two or three maintenance men at a rate of $100 per day per man. This charge is in addition to the basic fee for the boat [22].

The more sophisticated submersibles, such as Beaver IV, and Deep Quest require a support crew of 8 and 11 men respectively when used on extended cruises. The charge for the charter of the vessels includes the fee for this crew. It can be seen that this number of people can very quickly fill the berths allocated for the scientific party. For example, the T-AGOR class of research vessel has berths for a scientific party of 15. This ship was designed with an option of being utilized to support a submersible. The ability to routinely make oceanographic stations with ships similar to the T-AGOR while the submersible and its crew are embarked must be evaluated as nil, due to lack of an adequately sized scientific party. The loss of the data that would have been collected during transits must be considered in the price of utilizing a submersible.

The value of the oceanographic data that is routinely collected, such as salinity, temperature profiles, meteorological and wave data has not been given a fiscal evaluation. This data is usually submitted to the national data bank to be employed in a variety of manners. The minimum value of this data will be placed at the cost of its collection, that is, the cost of the operation of the vessel and the crew that would be required to obtain it.

The economic comparison of the submersible with some other instrument suite should consider reliability, weather, time on station to accomplish the task, transit time to station, and cost of lost data.

The reliability of the submersible and its installed equipment has tended to decrease with the increased sophistication. Busby and Costin [16] provided a compilation of malfunctions experienced during chartered operations. It can be seen that the basic Perry submarine has had excellent reliability. The Aluminaut, a sophisticated platform, has experienced several failures. The technical nature of the failures seems to indict the electrical systems. The reliability of these systems might improve. Technical advances will necessitate the continuous updating of installed systems with the resultant threat to reliability being ever present.

The instruments used on the submersible have been assumed to have the same order of reliability as those used from the surface ship, but the submersible staff has shown its reliability to be less than that of the surface ship. This is due to the built-in duplication of capability that is present on the ship which, due to space consideration, has not been provided on the submersible.

The loss of time on station due to bad weather can be reduced by planning. Climitological atlases and long range forecasts, when properly evaluated, can allow the proposed operation to be scheduled in those time periods which have sea states that will not interfere with diving.

The cost of the submersible operation can be formulated as follows:

$$\text{Submersible Cost} = TT \times LR_T + \left(\frac{ST}{R \times W} - ST\right) \times LR_T + ST \times LD_d + LD$$

TT = transit time
LR_T = transit lease rate
LD_d = diving day lease rate
ST = station time required to accomplish mission
R = probability of no equipment failure

W = probability of satisfactory weather for operation
LD = cost of lost data

The submersible, to gain an economic advantage over any option, must be operated on missions which minimize its expense and maximize its utility. The above equation has indicated transit time is extremely costly. The submersible missions that are conducted on the continental slope and shelf are conducted in a region that can be exploited economically and has low transit time. Similarly, missions that would have replaced several surface sampling operations in one dive, such as a complete site survey with multiple cores, photographic coverage, and visual observation, have given an economic advantage to the submersible.

The submersible is leased to dive. An examination of the cost per dive of various contracts will reveal the daily rates tabulated in Table III do not truly represent the expenditure of funds required in utilizing a submersible for a mission. Table IV presents cost data concerning the operations of submersibles under contract to the Navy [18]. It stated the major reason for the variance in the cost per dive was the transit times.

It should also be noted variance was not a function of the leasee since Aluminaut dives at $11,650 per dive and $19,760 per dive were both sponsored by the Naval Oceanographic Office.

When utilizing the submersible, every effort must be made to economize. The effects of transit time in the cost of an operation have been clearly indicated. The non-representative example of $63,500 for one dive by DOWB, is at a rate much beyond the fiscal capability of the oceanographic community to support.

TABLE IV

RANGE OF COST OF A SUBMERSIBLE LEASE

Name of Vessel	Cost per Dive			Approximate Daily Lease Rate
	High	Low	Mean	
Deepstar 4000	$13,100	$ 3,145	$ 7,720	$5,000
Aluminaut	19,760	11,800	14,550	2,500-16,000
Star III	9,680	4,720	7,040	2,500- 4,500
Star II			2,500	2,000- 2,500
PC3B	1,910	667	1,110	400
Pisces	2,800	2,240	2,450	

2. The Cost of Ownership

There are few examples of an oceanographic research institution that have owned and operated submersibles. Table III has listed the cost of purchase or construction of several typical vessels.

The University Museum of the University of Pennsylvania operated the submersible Asherah in support of its archeological work. The vessel was found to be well suited for this mission [12]. Reference 38 stated that due to "unreasonably high insurance and relatively infrequent use," the submersible was sold to Technoceans, Inc. This company intends to lease Asherah for various missions.

No other example was found where research institutions owned and operated a submersible. Several submersibles have been donated to them, but there is no evidence to indicate that operations were undertaken.

When the submersible is owned, the annual fees for maintenance and operations plus the cost of insurance and consumables must be considered. The cost of maintenance and operation for an Alvin type vehicle was placed at $1 million per year [34].

The submersible, like all ships, can have limited availability due to maintenance and holiday considerations. The 365 day is reduced by Sundays, Saturdays, holidays and the need for about 60 days of maintenance to 193 operating days per year [26]. With the best of scheduling, this can be further reduced by weather and equipment failures so that a 150 operating day schedule for a submersible would seem normal, or about $6,000 per dive day based on the million dollar per annum rate. This is close to the lease rate of vessels similar in ability to Alvin such as Deepstar 4000.

The insurance costs for submersible operations were mentioned as a factor in Asherah's fate [38]. The figure of $635 per dive was the quoted insurance rate for DOWB [1]. The other lease rates indicated insurance was included in the figure presented. The insurance rate for DOWB was 20% of the total daily lease rate.

An effort to combat the high cost of owning a submersible, Guppy, a tethered, 1,000 foot vessel, was designed. It is commonly referred to as a $100,000 product. Sun Shipbuilding Company [27] placed the price for Guppy at $148,000 for the basic vehicle, plus two 1,000 watt lights, one variable shot hopper and 1,200 feet of umbilical cable. The cost of the lead shot is $25.00 per 100 pounds, this is used when lifting an object with Guppy. The power package of a 36 kilowatt generator and cable keel is an extra $15 to $20 thousand.

3. Why the Submersible has been Built

To understand the reasons for the construction of the fleet of submersibles, which now exist, it is necessary to consider developments during the last decade. This period contained the space race and the technological growth that accompanied it. Large firms vied for space contracts, and in order to attain the variety of competence required, they acquired other companies through mergers or the formation of conglomerates. The General Dynamics Corporation is a typical example with its variety of holdings ranging from aircraft production plants to a shipyard that specialized in the construction of nuclear submarines.

In 1963, a national tragedy, the loss of the submarine Thresher exposed the lack of ability to explore the ocean depths and the generally sad state of affairs concerning rescue of submarines in distress and knowledge of the ocean bottom. A program, the Deep Submergence Systems Project (DSSP), was initiated within the Navy for the purpose of lessening this knowledge gap. The DSSP was divided into four areas, (1) submarine rescue, (2) ocean search, (3) small object recovery, and (4) large object recovery. The technology to achieve the aims of each area was not yet developed and it was believed that the DSSP would provide an attractive region into which a company could direct its activities with expectation of long term development and profit.

The DSSP required a submersible to be developed to support each area. The implementation of the program was to take place over several years with each area having a prime contractor. The failure to gain the initial contract, development of a deep submergence rescue vehicle (DSRV), did not destroy a firm's opportunity to gain the contract for one of the follow-on vehicle contracts such as the Deep Submergence Search Vehicle (DSSV).

The aero-space firms saw the DSSP as an attractive business opportunity. It provided them with the opportunity to become involved with the production of an item, the submersible, which utilized the firm's potential in many areas, such as metalurgy, electronics, human factors engineering and precision manufacturing. In addition, it placed the firm in the field of oceanography. The literature had widely hailed the oceans as the "last frontier" for exploration on the earth and discussed the mineral wealth as well as the potential for providing food. Firms could diversify into the ocean with a high visibility product and little investment of its own funds. They became ocean oriented without necessarily acquiring ocean knowledge.

4. Profit Expectations

The profit expected to be gained from the submersible, was from (1) the lease or sale of the submersible, (2) knowledge gained to allow the winning of major contracts for submersibles such as DSSP, (3) corporate image improvement by involvement in oceanography, and (4) tax write off from losses associated with the submersible if it is not a commercial success.

(1) The first motive is direct and to some extent predictable. The corporations that have gained in this area are generally shallow divers, going to depths of 1200 feet or less. Therefore they work in regions that have legal status. The Perry submersibles are typical examples, they have wide application in oil field work and have received some utilization in marine science. They were built at a relatively low price so they would be competitive with other systems for under sea pipe inspection and maintenance. The commercially successful vessels, generally, have stressed the idea of the work boat rather than seeking

government research contracts. This would be typical of Pisces, and the Shelf Diver design.

(2) The second motive is associated with the profit from lessons learned. These could be directly associated with the submersibles or products developed during the research and development leading to the vessle. For example, the lessons learned from producing a submersible, similar in performance to the contract winning proposal for DSRV, would greatly improve the chance of gaining the follow-on program. This vehicle would provide a company owned platform for test and development of advanced systems. It would also be a measure of the effectiveness of the engineering design and cost estimates for refining follow-on proposals. The federal government has normally considered proven performance when awarding contracts rather than basing the decision solely on low cost bids. Westinghouse [40] provided a discussion of their effort in this area. Deepstar 20,000 was the result of design work for the DSRV contract. Westinghouse did not gain the contract but had a feasible design for a submersible which they would be able to produce in less time than would be required for the DSRV to become operational since the government with its contract administration and change orders would not affect progress.

(3) It is difficult to express in dollar terms the benefits a company might assure to its corporate image by expanding into the field of oceanography. In the early 1960's this was a great potential [4 and 39]. To date most adventures in the ocean are an extension of on-shore operations onto the continental shelf. What the ocean holds in the future can only be conjectured; however, the dwindling resources on the earth will require massive efforts in the ocean. Those companies that

undertake the initial efforts might find they are to the ocean what General Motors is to the automobile industry or International Business Machines is to the computer industry. Having been associated with oceanography has implied that the corporation was forward looking and interested in long range market development.

(4) The profit from the tax write-off of R&D costs or losses associated with a submersible that was a commercial failure are difficult to determine. The information required to discuss this topic in depth was not available from the corporations that have constructed submersibles.

The corporate tax structure is such that large tax benefits can be gained from business losses. The company can structure the staff for the submersibles operations to allow the overhead to be high, maximizing the loss during the depreciation period for the vessels. The large staff could provide services to other sections of the company at low internally regulated prices allowing some other portion of the firm to gain benefits while the submersible provides the high loss needed for tax purposes. By-products of the development of the submersible may be marketed in an advantageous position by assigning development costs to the submersible rather than the product.

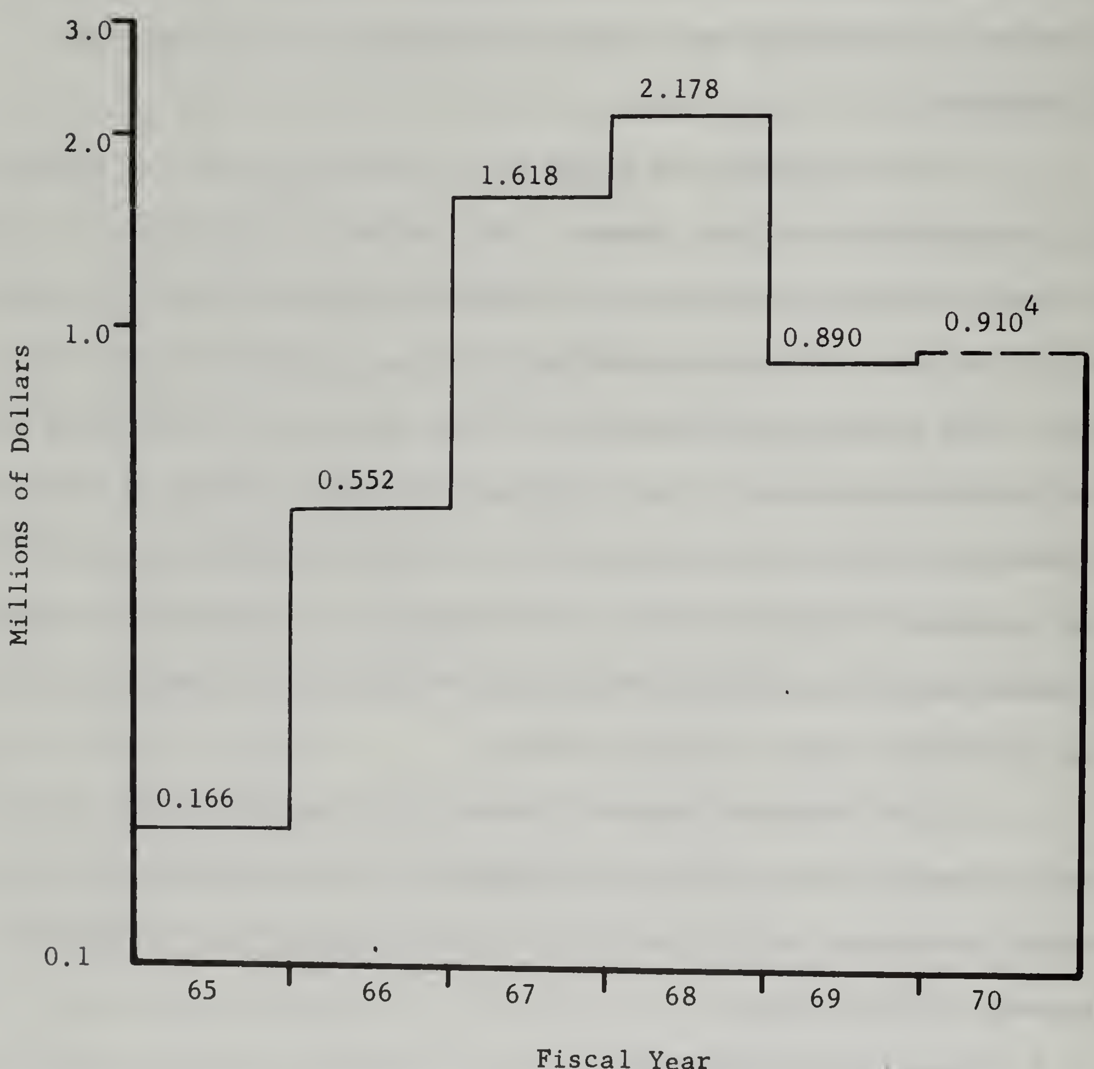
The numerous manners in which a firm can be managed to gain the tax benefits from the lack of success by the submersible and gain profit from the opportunities provided by the submersible are beyond the scope of this paper.

5. Demand for the Product

The government utilization of submersibles rose rapidly in the period from 1965 to 1968 as shown in figure 1, and the outlook was

FIGURE 1

NAVY LEASE OF SUBMERSIBLES FROM COMMERCIAL SOURCES



[4] Estimated [Ref. 18].

promising for research contracts. However, in this period the cost of the war and pressures for social reform caused a re-appraisal of government programs resulting in a decline in the rate of growth of the non-defense research market over the last two years as marine science programs were assigned lower priorities. This has caused a reduction in submersible utilization since 1968 by the government. An additional factor that has affected the downward trend of the submersible market was the construction of a pool of submersibles, including NR-1, Dolphin, Turtle and Sea Cliff by the Navy. These vessels have sharply reduced the lease role of the organization that had previously been the major source of submersible support. The current extent of the Navy's role in the commercial field is two salvage contracts, one on each coast.

The above statements concerning motivation into the submersible market and its status have been general. More specific examples of the cause for entry into the market follow.

Reynolds International entered the submersible field to demonstrate the capability of their product, aluminum, in a field that had been dominated by steel. They were able to produce the deepest diving submersible on the commercial market and the vessel has held this distinction since 1965. The only commercial vessel under construction that will exceed the depth of Aluminaut is Deepstar 20,000.

Similar efforts to demonstrate the advantages of the use of glass in a submersible have been undertaken. The Corning Company has co-sponsored many of these efforts. The glass has the potential to provide a combination of strength and visibility not available with other structural materials.

It can be seen that profit has taken many forms. No examples were found where a firm had underwritten the long term use of a submersible to further the knowledge of the oceans with little expectation of a positive return to the company.

6. The Effects of not Using the Submersible

The lack of utilization for the submersible has had an effect that is immediately obvious; the vessels have been laid up. During the period of investigation for this paper, approximately six months, the following submersibles have changed status; Deepstar 4000, Star II and Star III have been laid up, Beaver IV has been idled, Deep Quest activities have been cut back, and the only submersible operated by an educational institution, Asherah, was sold to a private concern. Effects that are perhaps more significant than the loss of these submersibles are (1) the loss of ocean experienced talent that was associated with submersibles, and (2) the reaction of the investor to the failure of these ocean ventures.

The cost of the loss of ocean experienced talent in marine science due to the laying up of the submersible cannot be directly evaluated in terms of dollars. Its effect on progress in marine science will be felt in that expensive lessons of the past will have to be learned again and in the increased wages that will have to be paid to attract the experienced scientists and engineers back into the field of oceanography.

The reaction of the investor to the failure of the submersible as a commercial venture is complex. The firms that have had to shut down their vessels have generally been large corporations whose success will not be greatly affected by the submersible operation. They are not

generally associated with oceanography. For example, General Dynamics and Westinghouse's corporate image was not greatly affected by laying up of the vessels. It is doubtful if most of the stockholders in these firms are even aware of this action. Rather, the problem arises from the use of submersibles being assigned the role of an indicator of the attractiveness of investment in ocean oriented firms. Recent articles in business and management magazines have addressed these firms as a possible area for investment. These articles have assessed the laying up of the submersible as a symptom of poor profit potential in the short term for all ocean oriented business [31]. The magazines do not attempt to discourage the long term investor, however, current market conditions have done this.

The exploitation of the ocean's resources depends on an orderly development of the equipment and techniques that will be required to assault this hostile environment. The withdrawal of the private sector's support at this juncture on the recommendation of an interpretation of the role of the submersible can have serious affects. A $3 million subsidy which was proposed and withdrawn from the defense budget might have kept several of the laid-up vessels active and counteracted the impression that has been gained by these business writers.

V. CONCLUSIONS

A. SUMMARY

The paper has reviewed a balanced national effort for marine science which has been proposed in "The Stratton Report." This report has delineated national goals which emphasize increasing the base of oceanic knowledge and simultaneously seeking economical means of exploiting the ocean to meet the demand for resources whose land supply has been or is nearing depletion.

This effort has been converted into specific programs with data requirements that provided potential roles for the submersible. These roles were discussed in relation to the scientific disciplines associated with oceanography. The submersible was found to have unique capabilities to collect the required data for several of the programs. These capabilities were associated with missions that could be included under national security.

Research and development funding for the submersible has been primarily sponsored by the Navy. A large federal program, DSSP, has provided motivation for the construction of several of the vessels, however, the recent revolution of national priorities has reduced the extent of this program and the utilization of commercial vessels.

The Navy has constructed submersibles which have the potential to accomplish the data collection required by the national effort, further reducing the market for the commercial submersible in marine science.

To off-set the loss of a market for the submersible, a subsidy has been proposed which would finance submersible services for scientific

missions. This subsidy would tend to keep a competitive pool of vessels available for marine science. To date the subsidization of submersibles has not been placed in effect and current information indicates that it will not be.

The submersible has non-scientific roles which provide it with a potential expanding market. These roles are associated with recreation, salvage, and mechanical work on off-shore facilities. The rate of expansion of these roles is limited by the lack of a legal status for the ocean floor. Pending a determination of a code of laws for this area, about sixty percent of the surface area of the earth, commercial expansion off the continental shelf will be limited due to the uncertainty of a firm being able to profit from its investments.

The potential of the ocean to provide a profit to a firm will continue to attract investments regardless of the failure or success of the submersible. The subsidy would be an attempt to support these ventures beyond their usefulness.

B. GENERAL CONCLUSIONS

The submersible has unique capabilities to perform work that is essential to attaining the national goals in the ocean. Most of these unique roles can be associated with national defense, thus the Navy's vehicles can be assigned to accomplish them.

The lack of a legal code for the ocean floor, beyond the continental shelf, has reduced commercial exploration and exploitation of the non-living resources of the ocean. This has eliminated a portion of the commercial market for the submersible.

The unique roles of the submersible in marine science have been diminished as technology has provided more sophisticated instruments which can accomplish the same tasks with control from a surface vessel, for example, recently real time viewing of the bottom has been provided to a depth of 20,000 be television.

C. SPECIFIC CONCLUSIONS

The unique capabilities of the submersible which are required to support the national effort are the ability to:

1. Conduct hard rock coring of selected outcrops to provide substrata information vital to geologic maps.
2. Conduct controlled "in situ" tests to determine the engineering properties of the sediments and collect conventional samples in the immediate area for laboratory test correlations.
3. Conduct experiments at the water-sediment interface in which the alignment of the test instrument has great significance, for example, bottom heat flow and acoustic studies.
4. Assist in the identification of bio-acoustic sources.
5. Provide a mobile platform for acoustic instruments with the necessary alignment information available.
6. Conduct experiments that involve collection of a complete set of measurements and samples simultaneously at one depth.
7. Conduct "in situ" evaluations of material performance where the sample is affected by all the elements of the hostile environment of the ocean while the sample is in a configuration similar to its potential use.

The submersible is an expensive instrument platform, however, it can be made economically competitive with other vessels by reducing transit periods. Missions that collect a large amount of data in one locality such that multiple stations would be required from a surface vessel, also are missions where the economic efficiency of the submersible would be enhanced.

VI. EPILOGUE

With limited funds, the role of the submersible in marine science has tended to diminish. If additional funds should become available, an expansion of programs might increase the use of the vehicle. The private sector will not provide these funds due to the problems associated with the question of the ocean-bottom legal status. The Federal Government has given higher priority to other programs, for example war on crime, public health and the war in Viet Nam. When additional funds become available, some of the conclusions of this paper will be invalidated.

APPENDIX A

THE NATIONAL INVOLVEMENT IN OCEANOGRAPHY[6]

In 1966, the Congress initiated a comprehensive study of the nation's involvement in marine affairs. It was hoped that this would provide coherence to the multitude of efforts that were being conducted by the federal agencies to develop our potential to utilize the ocean. The study group, chaired by Dr. Julius A. Stratton, Chairman of the Ford Foundation, was composed of specialists in ocean sicences, engineering, national security affairs, economics, foreign affairs and public administration. It was to assist the President in identifying government-wide goals and in developing strategies for their achievement.

The Stratton Committee recognized the need to conduct the research that would provide the basis for understanding the complex relations that shape and control the ocean as well as applying efforts to meet projected shortages of food and minerals. The recommendations of the report that it issued, are in many cases very specific; however, only the broad goals and programs are presented in order to allow a general familiarity with the federal effort.

NATIONAL GOALS

The goals are broad statements of purpose. They provide the criteria by which proposed programs may be evaluated. The six basic goals are presented in summary form.

---

[6] This Appendix has been developed from refs. 32, 33, and 35-37.

1. National Capability in the Sea

The nation must have the broad capability to satisfy the needs for scientific and engineering knowledge common to nearly all marine programs. The national program in technology and marine science should emphasize those activities basic to a wide spectrum of potential applications.

2. Management of the Coastal Zone

A management system, which would permit conscious and informed choices among development alternatives and provide for proper planning for more effective use of our coastline must be introduced. The present federal, state and local systems are inadequate for the task of preserving the region.

3. Marine Resources

Policies should be developed so there is no critical shortage of any raw material. These policies should advance economic efficiency in the development of all resources.

4. Global Environment

The effective use of the sea would require the capability to observe, understand and predict oceanic processes on a global scale. This would include data on the ocean's chemistry, biology, thermal structure, motion, and the characteristics of the bottom.

5. Technical and Operating Services

New technology must be brought to bear to provide general purpose mapping and charting, navigation safety, data management and instrument calibration.

6. <u>Organizing a National Ocean Effort</u>

A means of effective coordination of the national effort must be found. The formation of a federal organization for marine science affairs was urged.

The above list omits all of the detailed goals of the Stratton Report and the Panel Reports. As to submersibles, it stated a specific goal for the development and construction of exploration submersibles with ocean transit capability for civil missions to 20,000 foot depths. The 20,000 foot depth provides access to 98 percent of the ocean's floor, excepting only the deep trenches.

NATIONAL PROGRAMS

The nation hopes to achieve the goals by a series of programs. These cover a variety of efforts, however the principal programs are funded under thirteen headings.

The following summary discusses the area of interest of the program and the work being undertaken.

INTERNATIONAL COOPERATION AND COLLABORATION

This area has been listed first for the reason it has greater impact on the future development of the ocean than any other technological or economic program.

The lack of a body of law governing the sea floor beyond the claims of national jurisdiction has placed more than 50% of the surface of the earth, the sea bottom, in an extra-legal status. On 15 December 1969, the United Nations General Assembly passed a resolution that stated persons and states should refrain from exploiting the resources of the sea bed beyond the limits of national jurisdiction prior to

extablishment of an appropriate machinery to manage that region. It was further stated no claim to any part of this area or its resources will be recognized.

The establishment of machinery to provide for the efficient exploitation of the ocean must be accomplished to provide a stable environment for the investment and scientific communities. Pending the resolution of the status of the ocean floor, the expenditure of effort and funds in this area will be hampered by doubt concerning the ability to profit from ones efforts.

The question of the deployment of military installations on the sea floor has also been addressed by this program. The prevention of weapons systems being placed on the sea floor was the subject of a recent United States - Russian Treaty. This problem will continue to be treated in the future.

The funds allocated to this goal support the various international commissions that foster cooperation and administer the many fishing treaties, the International Ice Patrol and projects to foster the exchange of information between nations.

DEVELOPMENT OF THE COASTAL ZONE

The coastal zone is one of our most precious national assets. This region is populated by forty-five percent of our urban population and is the recreation center for many more people.

Current efforts to conserve our national heritage, to provide recreation, to foster commercial development and to dispose of heat and organic pollutants, place many sectors of society in conflict concerning this area. The coordination of these efforts is accomplished through a variety of programs.

The funds budgeted for the development of the coastal zone are used in the following six areas:

1. Development of commercial and sport fisheries
2. Enhancing recreation uses
3. Maintaining the quality of coastal waters
4. Resolving the questions related to coastal zone property, boundaries and uses
5. Strengthening policy planning, coordination and development of the zone
6. Encouraging research education and information.

The coastal zone includes the Great Lakes and Chesapeake Bay, as well as the oceanic zone.

NATIONAL SECURITY

This program consists of projects that are designed to maintain and improve the capabilities of our military forces to conduct their assigned missions. It can be divided into areas of emphasis as follows:

1. Surveying the properties of the ocean and ocean bottom
2. Marine science and technology in support of defense systems
3. Development of undersea search, rescue, recovery and man in the sea capability
4. Test and calibration facility
5. Marine science in support of the limited test ban.

These provide a large amount of data of use to non-military applications, which by itself would not have a high enough priority to be investigated.

The free exchange of information between the military and non-military sector is vital to the progress of the national effort. To

date this cooperation has existed and is assured in the future due to the large percent of the oceanographic effort that is controlled by the Federal Government. It has been estimated that 90% of the data collected by the Navy is unclassified and available to the public through the National Oceanographic Data Center (NODC).

FISHERY DEVELOPMENT AND SEA FOOD TECHNOLOGY

This program seeks to strengthen the fishing industry for economic development at home and aborad. This program is being conducted by the financing studies that will lead to greater production of the fish catch. It is also responsible for producing fish protein concentrate (EPC).

DEVELOPMENT OF NON-LIVING RESOURCES

This program has these areas of increasing emphasis. They are reevaluation of the legal-financial-administrative framework for oil and gas leases, establishment of environmental protection and the complete geological, geophysical and bathymetric mapping of the United States Continental Shelf.

This program has been involved with the petroleum and mineral mining operations and development of desalinization of water.

TRANSPORTATION

This program has the responsibility for rejuvenating our merchant fleet and port facilities. In addition, it has taken steps to reduce pollution caused by marine disasters, such as the sinking of the Torrey Canyon, and improving navigation systems.

NATIONAL DATA CENTERS

This program seeks to facilitate the collection and distribution of data. The National Oceanographic Data Center was established to serve this need. Steps are being taken to ensure wide dissemination of current marine science projects.

GENERAL PURPOSE OCEAN ENGINEERING

This program includes advanced engineering related to material, power, propulsion, soils, habitats and instrumentation. Specific projects include the development of Cable Controlled Underwater Research Vehicle (CURV III), and power sources for underwater tasks.

The National Instrumentation Facility, a center to provide prime standards and calibration techniques for oceanography, is funded by this program.

EDUCATION

The program consists of the Sea Grant Program which is administered by the National Science Foundation. This will provide a source of specially trained manpower for developing oceanographic programs and a base of institutions capable of research in marine sciences.

ENVIRONMENTAL OBSERVATION AND PREDICTION

The program is devoted to understanding and predicting the ocean environment. Areas of emphasis in this endeavor include the development of Buoy Technology and Spacecraft Oceanography.

OCEAN EXPLORATION, MAPPING, CHARTING AND GEODESY

The program seeks to provide knowledge of those features of the ocean that vary slowly with time. The program has a wide variety of

ships employed to obtain data for accurate charts. Among the methods being developed are experimental photogrammetric maps with closely spaced contour intervals from data obtained by submersibles.

HEALTH

The program has stressed research into marine bio-active substances and possible sources of new pharmaceutical products.

The Stratton Report has indicated another area of growing concern, the Arctic. The nation will seek to further economic development of the Arctic region in general and Alaska in particular, so that the United States will have a dominant role in that region of the world.

LIST OF REFERENCES

1. A. C. Electronics letter, serial S-295B to Professor R. J. Smith, Subj: Proposed Charter of R/V DOWB.

2. Beebe, W., Half Mile Down, Harcourt, Brace and Company, 1934.

3. Center for Naval Analysis Study 19, The Navy's Role in the Exploitation of the Ocean (Project Blue Water), V. 1, June 1968.

4. Committee for Oceanography, Publication 1228, Economic Benefits from Oceanographic Research, National Academy of Sciences, 1964.

5. "Dry Year for Submersibles", Oceanology International, p. 19, February 1970.

6. General Dynamics, Electric Boat Division letter serial 1146 to Superintendent, Naval Postgraduate School, Subj: Use of Star II, 16 May 1969.

7. Hull, E. W. S., "Those Remarkable Little Work Boats," Geo Marine Technology, V. 3, p. 21-40, May 1967.

8. Interagency Committee on Oceanography pamphlet number 18, Undersea Vehicles for Oceanography, Government Printing Office, 1965.

9. Javits, J. K., Hitch, C. J. and Robinson, K. T., The Defense Sector and the American Economy, New York University Press, 1968.

10. Markel, A. L., Adventures with Aluminaut, paper presented at National Aeronautic and Space Engineering and Manufacturing Meeting, Los Angeles, California, Oct 6-10, 1969.

11. National Council on Marine Resources and Engineering Development, Marine Research Fiscal Year 1968, 1969.

12. National Geographic Research Reports No. 419, Evacuation of a Byzantine Shipwreck at Yassi Ada, Turkey by F. G. Bass and F. van Doorninck.

13. National Petroleum Council, Petroleum Resources Under the Ocean Floor, 1969.

14. National Security Industrial Association, Ocean Engineering, V. 1, 1966.

15. Naval Oceanographic Office Informal Report 68-62, Design and Operational Performance of Manned Submersibles, by R. F. Busby, June 1968.

16. Naval Oceanographic Office Informal Report 68-82, Ocean Surveying from Manned Submersibles, by R. F. Busby and J. M. Costin, September 1968.

17. Naval Oceanographic Office Informal Report 69-15, Undersea Studies with the Deep Research Vehicle Deepstar-4000, by R. Merrifield, March 1969.

18. Navy Material Command letter MAT 0327/DUB to COMSUBDEVGRU 1, Subj: Navy Use of Commerical Submersibles; Information Concerning, 27 June 1969.

19. Ocean Systems Operations, North American Rockwell letter serial 69MA6075 to Professor R. J. Smith, Subj: Use of Beaver IV, 10 June 1969.

20. "Oceanography; Science of the Seventies," The Value Line, V XXII, p. 560-570, 17 February 1967.

21. Office of Naval Research Study, Report on Deep Submersibles, December 1969.

22. Perry Submarine Builders unserialized letter to Joseph King, Subj: Perry Submersibles, 12 January 1970.

23. Piccard, J. and Dietz, R. S., Seven Miles Down, G. P. Putnam's Sons, 1961.

24. Reynolds Submarine Services Corporation unserialized letter to Joseph F. King, Subj: Use of Aluminaut, 1 December 1969.

25. Roman, D. D., Research and Development Management: The Economics and Administration of Technology, Appleton-Century-Crafts, 1968.

26. Schlosser, A. J., "Navy Diving Service Leases," Naval Ship Systems Command Technical News, Vol. 17, p. 38-40, January 1968.

27. Sun Shipbuilding and Dry Dock Co., letter serial RHH/11 to Joseph F. King, Subj: Guppy Costs, 11 December 1969.

28. Stevens, R. O., Jr., "Undersea Workboat in the Gulf of Mexico Oil Fields," Ocean Industry, V. 4, p. 30-34, October 1969.

29. Symposium on Mineral Resources of the World Ocean, Proceedings, University of Rhode Island, 1968.

30. Terry, R. D., The Deep Submersible, Western Periodicals Co., 1966.

31. "The Future of Oceanography" Business Management, V. 37, p. 40-65, October 1969.

32. U. S. Commission on Marine Science, Engineering, and Resources, Our Nation and the Sea, U. S. Government Printing Office, 1969.

33. U. S. Commission on Marine Science, Engineering, and Resources, Panel Reports, U. S. Government Printing Office, 1969.

34. U. S. House of Representatives; Hearings of Department of Defense Appropriations for 1970, U. S. Government Printing Office, 1970.

35. U. S. President Marine Science Affairs, U. S. Government Printing Office, 1967.

36. U. S. President Marine Science Affairs, U. S. Government Printing Office, 1968.

37. U. S. President Marine Science Affairs, U. S. Government Printing Office, 1969.

38. University of Pennsylavnia unserialized letter to Joseph F. King, Subj: Asherah Operations, 21 November 1969.

39. University of Texas at Austin working paper 68-23, Marine Sciences and their Industrial Potential, by George Kozmetsky, 16 April 1968.

40. Westinghouse Report, Mission Definition - Deepstar 20,000, by A. Schwartz, 30 September 1969.

41. Woods Hole Oceanographic Institution Report 67-50, Geology from a Deep-Diving Submersible, by John Schlee, August 1967.

42. Woods Hole Oceanographic Institution Report 69-32, Hand Tools and Mechanical Accessories for a Deep Submersible, by C. L. Winget, May 1969.

43. "$7.4 million Ocean Simulation Facility Being Built," Oceanology International, p. 11, January 1970.

INITIAL DISTRIBUTION LIST

		No. Copies
1.	Defense Documentation Center Cameron Station Alexandria, Virginia 22314	20
2.	Library Naval Postgraduate School Monterey, California 93940	2
3.	Department of Oceanography Naval Postgraduate School Monterey, California 93940	3
4.	Oceanographer of the Navy The Madison Building 732 N. Washington Street Alexandria, Virginia 22314	1
5.	Naval Oceanographic Office Attn: Library Washington, D. C. 20390	1
6.	LCDR P. Tatro, USN Office of Naval Research Department of the Navy Washington, D. C. 20360	1
7.	CDR Don Walsh, USN 3334 Hawk Street San Diego, California 92103	1
8.	Dr. D. F. Leipper Department of Oceanography Naval Postgraduate School Monterey, California 93940	1
9.	Dr. J. W. Creighton Department of Business Administration and Economics Naval Postgraduate School Monterey, California 93940	1
10.	Dr. R. J. Smith Department of Oceanography Naval Postgraduate School Monterey, California 93940	1

		No. Copies
11.	Dr. E. B. Thornton Department of Oceanography Naval Postgraduate School Monterey, California 93940	1
12.	Mr. R. F. Busby Naval Oceanographic Office, Code 9120 Washington, D. C. 20390	1
13.	LCDR V. K. Nield, USN SMC 2410 Naval Postgraduate School Monterey, California 93940	1
14.	LCDR J. F. King, USN USS Long Beach CGN 9 Fleet Post Office San Francisco, California 96601	1

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

ORIGINATING ACTIVITY (Corporate author) Naval Postgraduate School Monterey, California 93940	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

REPORT TITLE

The Submersible and Oceanography

DESCRIPTIVE NOTES (Type of report and inclusive dates)

Master's Thesis; April 1970

AUTHOR(S) (First name, middle initial, last name)

Joseph Francis King

REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
April 1970	73	43

CONTRACT OR GRANT NO. PROJECT NO.	9a. ORIGINATOR'S REPORT NUMBER(S) 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

DISTRIBUTION STATEMENT

This document has been approved for public release and sale; its distribution is unlimited.

SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Naval Postgraduate School Monterey, California 93940

ABSTRACT

During a period of expansion of the nation's oceanographic effort, the submersible has seen a decline in utilization. This has resulted in several vessels being withdrawn from the market. The reasons for the lack of utilization of this oceanographic tool are studied in this paper.

The various national programs are examined to determine those data collection missions which require the unique capabilities of the submersible to utilize its ability to provide accurate alignment of instruments, conduct complex experiments "in situ" and core hard rock samples.

The submersibles failure to gain greater utilization results from its high cost and weather limitations and from the fact that its instrument suite does not provide a clear advantage over other methods of data collection.

It is concluded that the reduction of the pool of submersibles will not affect the progress of the nation's oceanographic efforts. Programs requiring such a vessel can be associated with national security, permitting research to be conducted with Navy operated submersibles.

It is also concluded the financial losses incurred by the owners of the submersibles will not deter further involvement by the private sector in the ocean development.

DD FORM 1 NOV 65 1473 (PAGE 1)

S/N 0101-807-6811

Security Classification

A-31408

Security Classification

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Submersibles						
Deep Submersibles						
Marine Economics						

DD FORM 1 NOV 65 1473 (BACK)

S/N 0101-807-6821

Security Classification

A-31409

16 DEC 70 19016
22 APR 71 18898

120009

Thesis
K446 King
c.1 The submersible and
oceanography.